

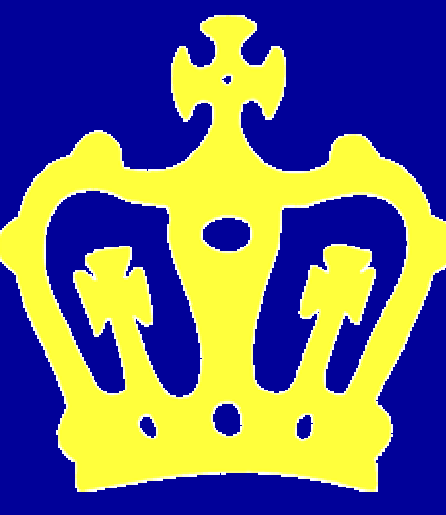
Multi-Phase Three-Dimensional Level Set Segmentation of Brain MRI

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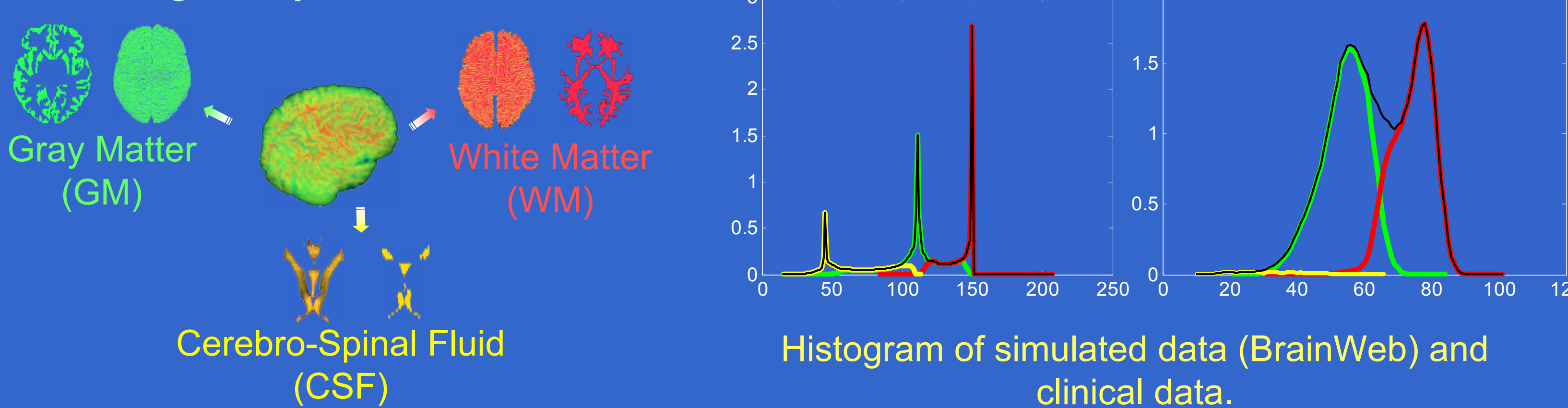
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1. INTRODUCTION

- Segmentation of cortical structures on clinical brain MRI data is applied for clinical study of depression on elderly subjects.
- Segmentation of clinical MRI data is more challenging than with simulated data due to intensity overlap among cortical structures and non-homogeneity within each tissue.



2. METHODOLOGY

2.1 Homogeneity-Based Energy Functional

- An active contour model proposed by Chan and Vese [1] derived from the Mumford-Shah functional with regularizing terms defined for a curve C as:

$$E = \mu(\text{length}(C)) + \nu(\text{area}(\text{inside } C)) + \lambda_1 \int_{\text{inside}(C)} |u_0 - c_1|^2 dx + \lambda_2 \int_{\text{outside}(C)} |u_0 - c_2|^2 dx$$

c_1, c_2 : mean values of the image inside and outside the curve C .

$\mu, \nu, \lambda_1, \lambda_2$: fixed parameters.

- This energy functional can be extended to the segmentation of multiple homogeneous objects in the image by using several curves $\{C_1, C_2, \dots, C_n\}$. In the case of two curves, the energy functional is defined as:

$$E = \lambda_1 \int_{\text{inside } C_1} |u_0 - c_{11}|^2 d\Omega + \lambda_2 \int_{\text{inside } C_2} |u_0 - c_{10}|^2 d\Omega + \lambda_3 \int_{\text{outside } C_1} |u_0 - c_{01}|^2 d\Omega + \lambda_4 \int_{\text{outside } C_2} |u_0 - c_{00}|^2 d\Omega + \mu_1 \text{length}(C_1) + \mu_2 \text{length}(C_2) + \nu_1 \text{area}(\text{inside } C_1) + \nu_2 \text{area}(\text{inside } C_2)$$

2.2 Level Set Formulation of Optimization Problem

- The curve C is embedded in a level set function ϕ , with its associated Heaviside function H and Dirac function δ defined.

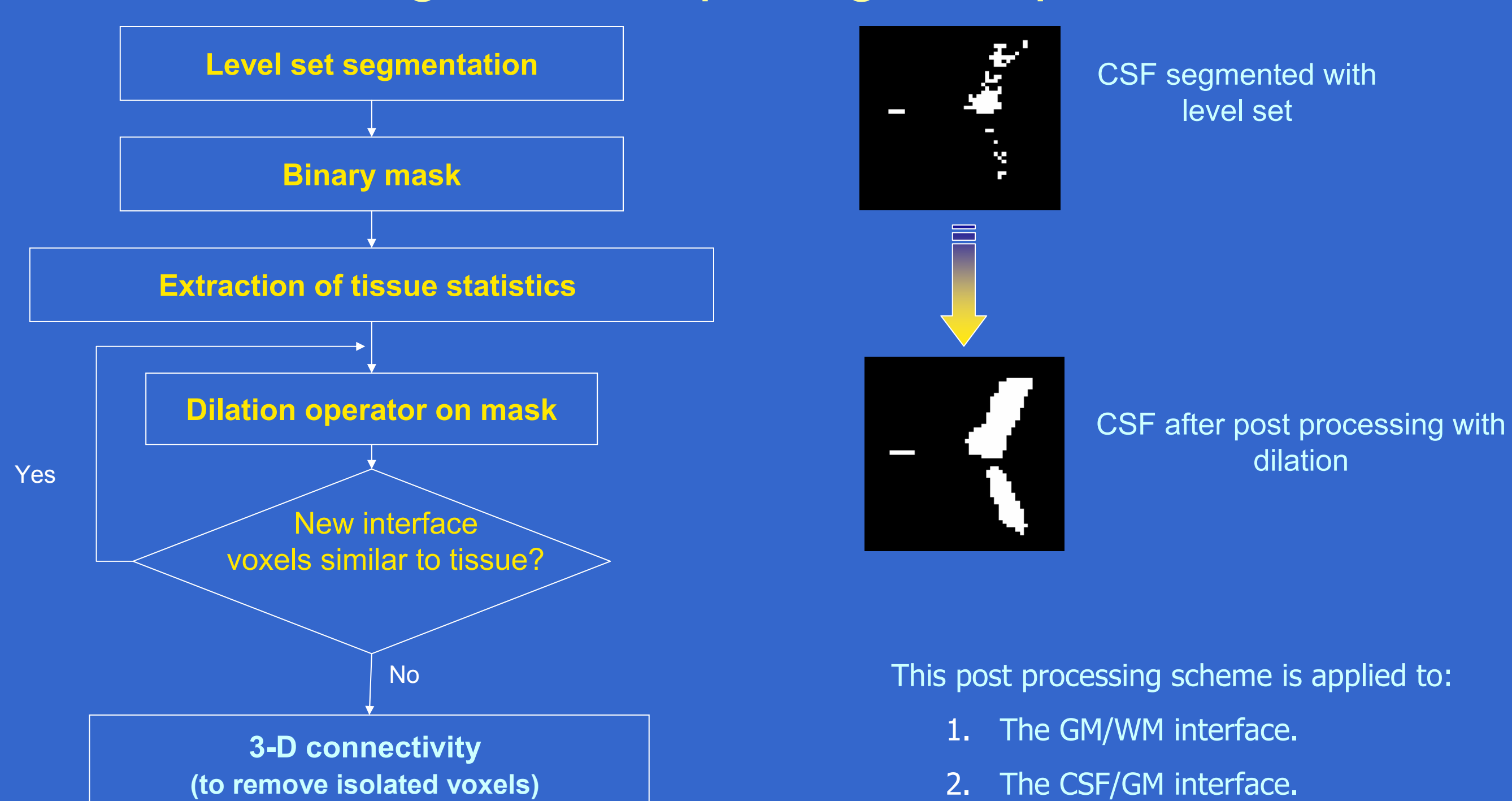
- The Euler-Lagrange system for the two level set functions is:

$$\frac{\partial \phi_1}{\partial t} = \delta(\phi_1) \left\{ \mu \text{div} \left(\frac{\nabla \phi_1}{|\nabla \phi_1|} \right) - \nu + \lambda_1 (u_0 - c_{11})^2 H(\phi_2) + \lambda_2 (u_0 - c_{10})^2 (1 - H(\phi_2)) \right. \\ \left. - \lambda_3 (u_0 - c_{01})^2 H(\phi_2) - \lambda_4 (u_0 - c_{00})^2 (1 - H(\phi_2)) \right\}$$

$$\frac{\partial \phi_2}{\partial t} = \delta(\phi_2) \left\{ \mu \text{div} \left(\frac{\nabla \phi_2}{|\nabla \phi_2|} \right) - \nu + \lambda_1 (u_0 - c_{11})^2 H(\phi_1) - \lambda_2 (u_0 - c_{10})^2 H(\phi_1) \right. \\ \left. + \lambda_3 (u_0 - c_{01})^2 (1 - H(\phi_1)) - \lambda_4 (u_0 - c_{00})^2 (1 - H(\phi_1)) \right\}$$

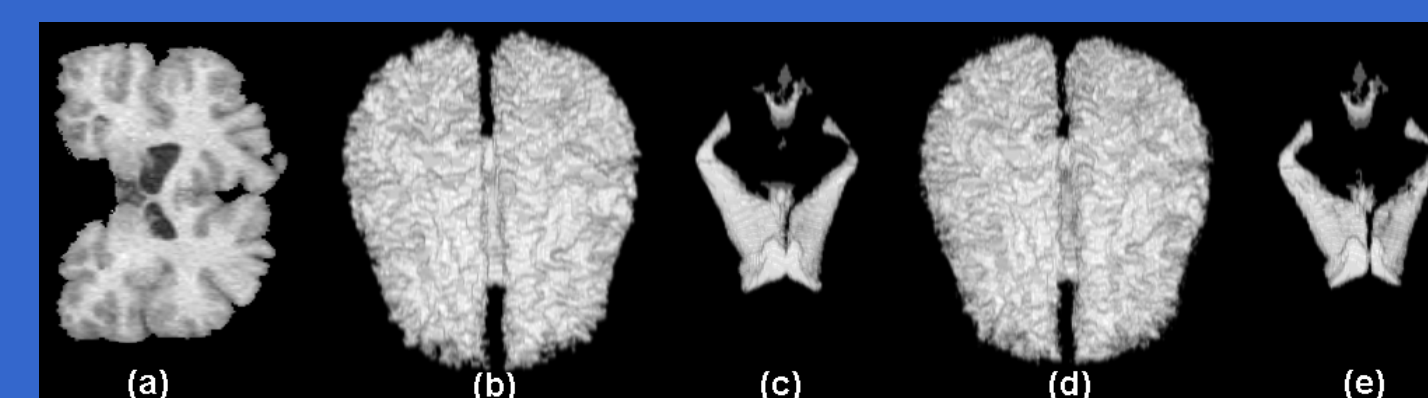
- Initialization: Two sets of 64 cylinders centered at regularly spaced seed locations, slightly shifted. Such initialization does not use any *a priori* information, is fully automated and provides robustness of the iterative optimization to local minima.

2.3 Post Processing With Morphological Operators



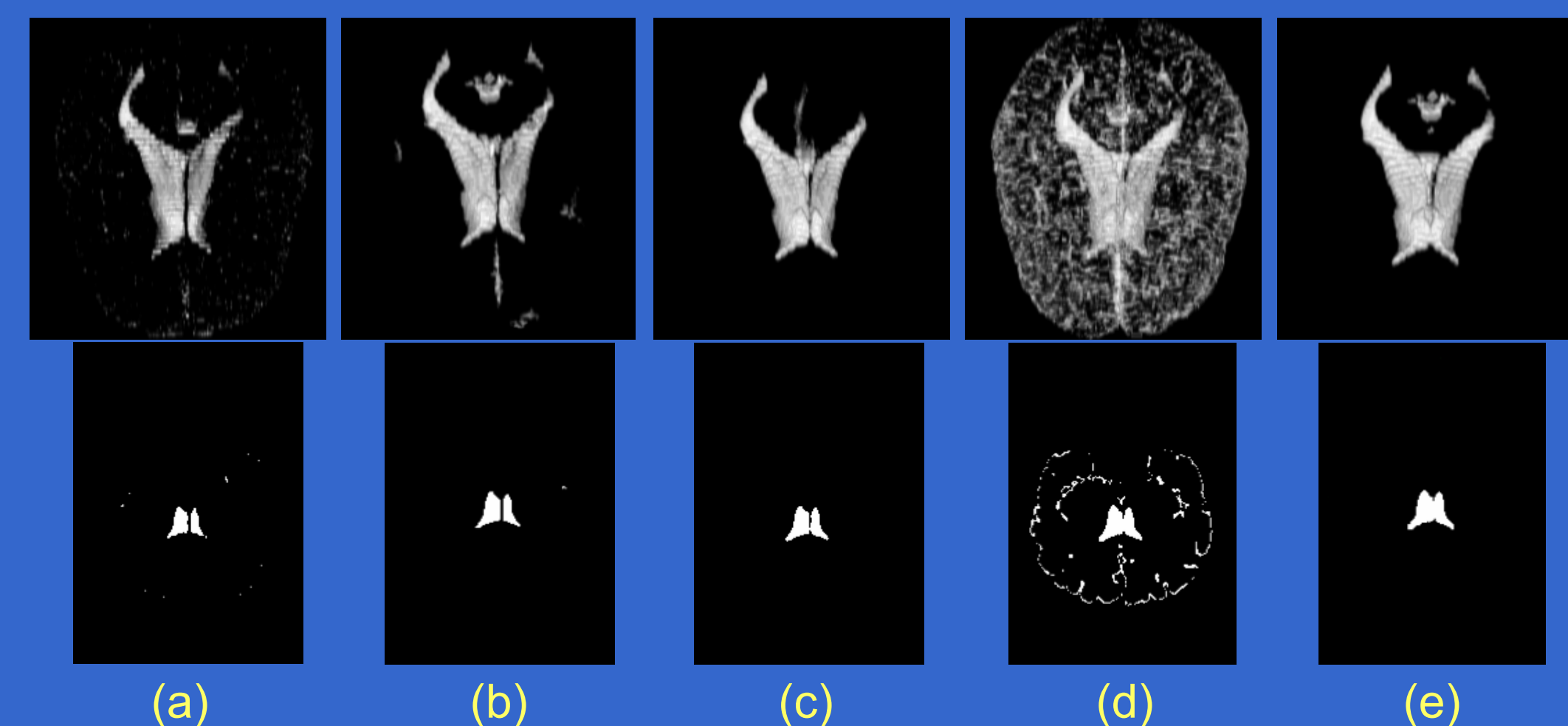
3. EXPERIMENTS AND RESULTS

- The segmentation method was applied to ten T1-weighted MRI data sets of healthy young volunteers, of size 256x256x73 with a 3mm slice thickness and 0.86mm in-plane resolution.

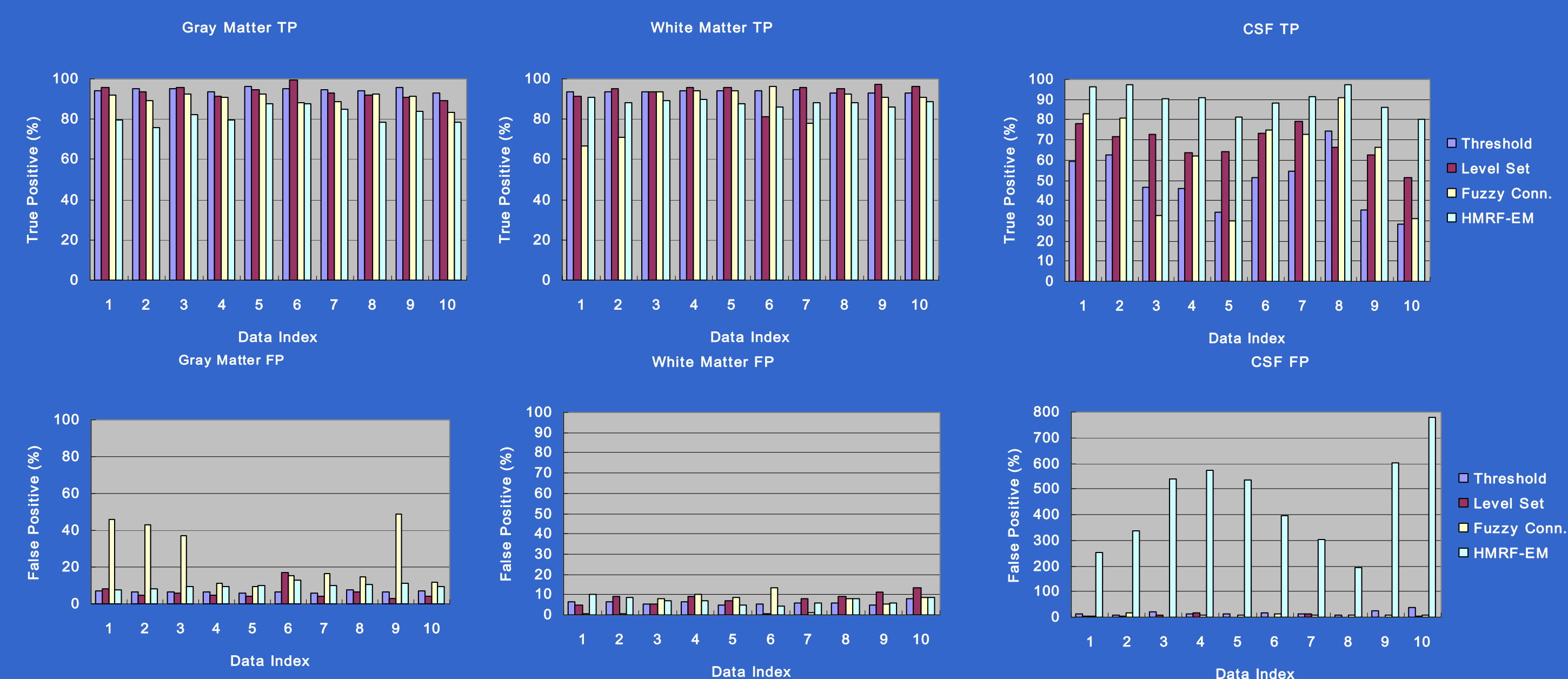


(a) MRI data. (b-e) Rendering of WM and CSF structures: (b-c) with manual labeling, (d-e) with multi-phase level set segmentation.

- Accuracy of the multi-phase level set segmentation was compared to histogram thresholding, fuzzy connectedness, and HMRf-EM segmentation methods using the methodology from Udupa *et al.* [2]. Detailed results of this study are reported in [3].



Segmentation of the CSF. (a) Histogram Thresholding, (b) Level set, (c) Fuzzy Connectedness, (d) HMRf-EM, (e) Manual labeling.



True positive and false positive bar plots of the four segmentation methods for GM, WM and CSF.

4. CONCLUSIONS

- Multi-phase level set segmentation framework was applied to clinical brain MRI for segmentation of cortical structures.
- A post processing scheme, based on morphological operators, was applied.
- A clinical study on 10 healthy cases was performed comparing the performance of four segmentation methods to manual labeling.
- Superiority of the proposed multi-phase level set and post processing method was observed using a simple computational set up.

5. REFERENCES

- L. A. Vese and T. F. Chan, "A multiphase level set framework for image segmentation using the Mumford and Shah model," International Journal of Computer Vision, vol. 50, No. 3, pp. 271-293, 2002.
- J. Udupa, V. LeBlanc, H. Schmidt, C. Imielinska, P. Saha, G. Grevera, Y. Zhuge, P. Molholt, Y. Jin, and L. Currie, "A methodology for evaluating image segmentation algorithm," SPIE Conference on Medical Imaging, San Diego CA, USA, pp. 266-277, 2002.
- T. Song, E. D. Angelini, B. D. Mensh, A. Laine, "Comparison Study of Clinical 3D MRI Brain Segmentation Evaluation," 26th Annual International Conference IEEE Engineering in Medicine and Biology Society (EMBS), San Francisco, CA, USA. September 1-5, 2004.